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DERIVATION OF ACOUSTIC CRITERIA FOR THE CASSINI SPACECRAFT AND COMPARISON WITH FLIGHT DATA

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ABSTRACT

Acoustic measurements from eight pre-Cassini Titan IV flights, and an acoustic test of a Cassini simulator and Titan payload fairing (PLF), were used to derive acoustic flight and test criteria for the Cassini spacecraft. The flight and ground test data were used or modified to account for the following factors: (a) noise-spike contamination of flight data, (b) spatial and flight-to-flight variations of flight data, (c) application of a thicker barrier-blanket to the PLF for the Cassini mission, (d) effects of locating two Cassini assemblies, the Huygens Probe, and the High Gain Antenna (HGA), near the PLF, and (e) higher thrust of upgraded Titan solid rocket motors (SRMs) for the Cassini mission. An overall sound pressure level (OA SPL) of 145 dB was verified for the protoflight acoustic test criteria for the Cassini spacecraft. Cassini flight liftoff data showed an average OA SPL of 133 dB.

INTRODUCTION

The Cassini spacecraft (Figure 1) was developed at the Jet Propulsion Laboratory (JPL) and its suppliers for the National Aeronautics and Space Administration (NASA) to explore the planet Saturn, its rings, and its moons. NASA Lewis Research Center (LeRC, now John H. Glenn Research Center) performed the integration of the spacecraft to Lockheed-Martin Astronautics' (LMA) Titan IV launch vehicle. The spacecraft was launched on a Titan IV with a Centaur upper stage on October 15, 1997. Cassini will arrive at Saturn in July 2004.

The electric power sources for the Cassini mission are three critical Radioisotope Thermoelectric Generators (RTGs). The RTG design was previously vibration qualified for the Galileo and Ulysses missions. After extensive analysis of available Titan IV acoustic flight data, JPL analysts predicted that Cassini's RTG vibration responses to its acoustic environment would exceed the test qualified limits of the RTG design, due primarily to RTG mounting, launch vehicle and spacecraft differences. To avoid a costly requalification of the RTGs, estimated at \$30 M, a major blanket development and test effort was funded by NASA LeRC to reduce the PLF interior acoustics and the subsequent vibration response. The new blankets resulted in a lower and acceptable acoustic and vibration environment for the Cassini RTGs.

ACOUSTIC TEST PROGRAM

To meet the needs of the Cassini mission it was necessary to develop new blankets to reduce the acoustic field in the difficult frequency range of 200 to 250 Hz, by 3 dB. A two-phase test program¹ was performed to develop and test verify the improved blankets.

Phase 1 consisted of evaluating new blanket designs by acoustic testing of flat panel blanket samples, which had the advantage that numerous designs could be quickly evaluated at relatively low cost. By proper interpretation of the absorption and transmission loss (TL) test data, the leading designs could then be chosen for further testing in Phase 2. Phase 2 would test the leading candidate designs and the baseline Titan IV blanket design in a full-scale cylindrical PLF. Although this testing was expensive, the effect of the blankets on reducing the PLF interior acoustics was measured with the appropriate flight-like boundary conditions and geometry. The need to verify the blanket's attenuation in a full-scale test was heightened by the fact that the frequency range of interest coincided with the PLF's ring frequency.

A total of 19 different blankets (18 new designs and the Titan IV baseline) were tested in Phase 1²⁻³. All materials utilized had to be already flight qualified. Of the 18 new blanket designs, two designs (noted as V5 and V10) were chosen for Phase 2 testing. Phase 2 test hardware consisted of a 60-foot high section of a Titan IV PLF, along with simulators of the Cassini and Centaur upper stage. The lower part of the spacecraft simulator was a high fidelity developmental test model (DTM) supplied by JPL. Included in the DTM were one RTG dynamic simulator and two RTG mass simulators. The upper part of the spacecraft simulator and the large High Gain Antenna (HGA) at the top of the spacecraft were simulators provided by LMA to represent the proper geometry and volume effects. Phase 2 consisted of 7 acoustic tests, which used 3 blanket configurations (Figure 2), to determine the acoustic and RTG vibration environments. The Phase 2 program was designed to measure the delta effect of the acoustic environments using new blankets compared to the baseline. Since the reverberant acoustic field of the test chamber is different from the external progressive acoustic wave during launch, it was felt that delta measurements,¹ not absolute, would be most meaningful.

To properly quantify this delta effect a large number of microphones (Figure 3) were utilized to measure the PLF interior acoustic field. Microphones were also located to measure the acoustic field for past and future Titan IV flights. A small number of accelerometers were mounted on the simulators to ensure that they were behaving normally. JPL and McDonnell Douglas Aerospace (MDA, now Boeing, Huntington Beach) also had a large amount of instrumentation to measure the vibration response of the spacecraft and PLF, respectively. The acoustic excitation on the PLF exterior simulated the Titan IV flight external specification.

The new blankets were very successful in reducing the PLF interior acoustics to levels below those provided by the baseline (Figure 4). The ultimate goal to reduce the RTG vibration response to prevent a vibration requalification of the RTGs was achieved. The acceleration spectral density at the base of the RTG dynamic simulator was substantially reduced, particularly in the 200-250 Hz region, by the utilization of either the V10 or V5 designs.

Among the many secondary objectives addressed during the Phase 2 acoustic testing were: (a) determining the effectiveness of the Cassini HGA in dividing the PLF interior into two distinct internal acoustics fields (the biconic and cylindrical sections above and below the HGA, respectively), and (b) determining the frequency range where the direct progressive acoustic field generated by the PLF exceeds the interior reverberant field, especially near the RTGs. Objective (a) addressed the issue of properly testing similar antennae and reflectors, whereas Objective (b) addressed the definition of which type of acoustic field, progressive or reverberant, should be used for spacecraft testing. Ordinary coherence data analyses⁴ were used for these purposes.

Figure 5 shows low coherence ($\gamma^2_{(4,6)} < 0.75$) for microphone pair (4, 6) of Figure 3, located close to and on opposite sides of the HGA, indicating two distinct fields. Thus, proper testing of the HGA should have been performed using two independent random sound sources, each with its own spectrum and confined to its own side of the structure by using a perimeter baffle

around the HGA. However at 43 Hz, coherence of $\gamma^2_{(4,6)} = 0.8$ shows significant coupling of the two fields. Figure 6 shows zero phase of the cross-spectrum at 43 Hz, indicating the instantaneous pressures across the HGA should be subtracted and the net structural loading reduced. These results have significant implication on future acoustic testing of large antennae and reflectors. Figure 7 shows high coherence between 30 and 250 Hz for internal microphone pair (23, 24) near one of the RTGs. Microphone 24 is located adjacent to the PLF/blanket (6-inch from PLF) and Microphone 23 is 18-inches from the PLF. Figure 8 shows close to zero phase between these two frequencies. Thus, below 250 Hz, the direct progressive acoustic field dominates. Low coherence below 25 Hz is probably due to electrical noise contribution. Above 250 Hz, low coherence indicates a reverberant field. A complete summary of the full scale cylindrical PLF testing may be found elsewhere.^{3, 5-13}

CASSINI BLANKET SELECTION

Phase 2 technical assessment showed that both the V5 and V10 barrier blankets had similar acoustic performances, exceeding the goal of reducing the acoustic environment by 3 dB and significantly reducing the RTG vibration response, at the key frequencies. No detrimental effects were seen at any frequency. NASA LeRC's Cassini Project Office selected V5 for Cassini. Besides the acoustic improvement, factors considered were the added weight of the blankets, and contamination, separation, thermal, venting, and clearance factors. With most considerations being nearly equal, the weight of the blanket became the deciding factor and the "lighter" V5 blanket was chosen over the heavier V10. The V5 blanket is four times the weight of the baseline.

CASSINI FLIGHT INSTRUMENTATION

The Cassini spacecraft was successfully launched from Cape Canaveral on October 15, 1997 on Titan IV Vehicle B-33. Flight data¹⁴ was provided by LMA's Pulse Coded Modulation (PCM) Wideband Instrumentation System (WIS). Of the total of 32 high frequency channels, 10 acoustic measurements were made, shown in Table 1 and Figure 9. Internal measurements 10003-10006 were considered Cassini unique. LMA analysts calculated 1/3 octave band (OB) SPL, for these microphones. Liftoff SPLs were calculated from maximum envelopes of 1-second time averages, with 50% overlap, over the 0 to 8 seconds liftoff duration.

Measurement Number	Description
9102	External, PLF Station 104, Azimuth 0, Centaur region
9103	External, PLF Station 104, Azimuth 180, Centaur region. Data Invalid.
9104	Internal, PLF Station 312, Azimuth 0, near Centaur Forward Adapter
9105	Internal, PLF Station 312, Azimuth 180, near Centaur Forward Adapter
9121	External, TTV Station 240, Azimuth 90, Compartment 2A region
9122	External, TTV Station 240, Azimuth 0, Compartment 2A region
10003	Internal, PLF Station 572, Azimuth 10, 18" Standoff above Cassini HGA
10004	Internal, PLF Station 521, Azimuth 10, 18" Standoff below Cassini HGA
10005	Internal, PLF Station 335, Azimuth 10, 18" Standoff near Cassini RTG
10006	Internal, PLF Station 335, Azimuth 10, Surface Mounted near Cassini RTG

Table 1. Cassini Flight Acoustic Measurements

CASSINI FLIGHT AND PRE-CASSINI FLIGHT DATA ANALYSIS

Figure 10 shows the 1/3 OB SPL of all valid acoustic data measured during the Cassini liftoff, plus some reference specifications. The higher family of curves represents the external flight data and the lower family shows the effect of the acoustic blankets and the PLF

structure's noise reduction on the internal flight levels. One (9121) external measurement has a lower SPL, due to its 90-degree azimuth and subsequent shielding from the SRMU (Solid Rocket Motor Upgrade). LMA's maximum predicted P95/50 specification at the surface for a Titan IV with SRMU baselines the external flight data. Prior to launch, the Cassini spacecraft and its hardware were qualified for flight by acoustic and random vibration testing. There were two acoustic specifications in the Cassini Interface Control Document (ICD), one for the spacecraft and another for the RTGs. The ICD specified the maximum predicted P95/50 free-field PLF internal environment (Figure 10). The RTG ICD specification is lower below 500 Hz, due to usage of the improved blankets in the RTG region. Actual flight acoustic levels did fall below the ICD levels. Microphone 10006 is PLF surface mounted and thus its field is higher than the reverberant field within the PLF.

Figure 11 shows the comparison of 3 Cassini PLF interior flight measurements versus preflight predictions.^{12,15} The prediction was derived by statistically analyzing 22 measurements from 8 previous Titan IV flights to determine the mean and P95/50 levels for a typical Titan IV flight with the standard SRM and baseline blankets. Cassini predictions were adjusted for the SRMU effect (+1 dB) and the expected decrease resulting from the utilization of V5 blankets (Figure 4). Measured flight data 10004, -5 and -6 (corrected to an 18-inch free field level) approximated the predicted mean up to 300 Hz, was lower than the mean between 300-1KHz and significantly lower above 1KHz. The real flight performance was actually better, since this analysis assumed that Cassini was a nominal Titan IV flight. As can be seen from Figure 10, the Cassini external flight levels were somewhat greater than nominally expected and exceeded the P95/50 level in the 50, 63, 125 and 160 Hz 1/3 OB.

High coherence and nearly zero phase below 250 Hz was observed in Figures 12 and 13, respectively, for flight Microphone pair 10005 and -6. These measurements generally confirm similar data (Figures 7-8) obtained during Phase 2 ground testing on the effect of microphone distance from the PLF wall. This conclusion is reached despite the fact the external acoustic field during ground testing was reverberant, whereas during the flight the field was progressive.

Other flight and ground test measurements were compared. In the full-scale acoustic ground test, Microphones 4 and 6 were above and below the HGA, respectively. For the Cassini flight, Microphone 10003 and -4 were above and below the HGA, respectively, at the same respective PLF stations as the ground tests. All four microphones were on 18-inch standoffs. The flight measurement pair was at azimuth 0 degrees and the ground test measurement pair was at azimuth 60 degrees, but this effect should be small as the PLF interior acoustics is a reverberant field. Flight coherence data above and below the HGA, similar to that obtained during Phase 2 acoustic ground testing (Figures 5-6), were examined. Flight coherence data were obtained using 5-second time windows to allow for the nonstationarity of the liftoff event. Figure 14 again shows low coherence, except at 50 and 230 Hz. Figure 15 shows nearly zero phase at these latter two frequencies. A detailed comparison of the SPL differences between measurements for flight and ground test has been made.¹

CONCLUSIONS

Cassini measurements, both on the ground and during launch provided the opportunity to investigate the spacecraft's acoustic field. Extensive testing was performed in a reverberant acoustic full-scale ground test primarily to address the acoustic performance of improved acoustic blankets. These tests verified that the new acoustic blankets met the goal of reducing the PLF interior acoustics in the zones of interest by 3 dB or more at the Cassini critical frequencies of 200 and 250 Hz. The V5 blankets were selected and flew successfully on the Cassini mission. Due to the improved acoustic blankets, the Cassini's RTGs did not have to be vibration requalified, resulting in \$30 M in savings.

The thoroughness involved with the ground test program provided excellent results and greatly contributes to the aerospace industry's knowledge of acoustics. Cassini flight measurements allowed the SPL generated in flight by a progressive acoustic field to be

compared with the SPLs generated by the reverberant ground acoustic field. Flight microphones were also chosen to investigate the effect of a large structure (HGA) on the PLF's interior acoustics, and the effect of standoff distance of the microphone from the PLF wall.

The preflight PLF interior acoustic levels were higher than that measured during the Cassini flight. Thus, a thorough acoustic reverberant ground test can qualify a spacecraft for its flight environment by a conservative amount.

ACKNOWLEDGEMENTS

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Thom Bergen is now employed at Wilson, Ihrig & Associates, Oakland, CA, USA.

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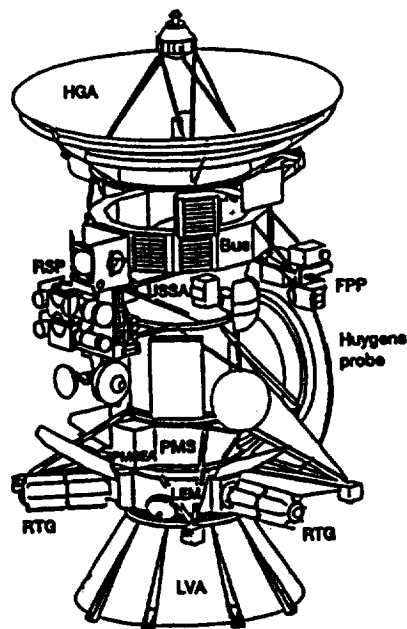


Figure 1. Cassini spacecraft.

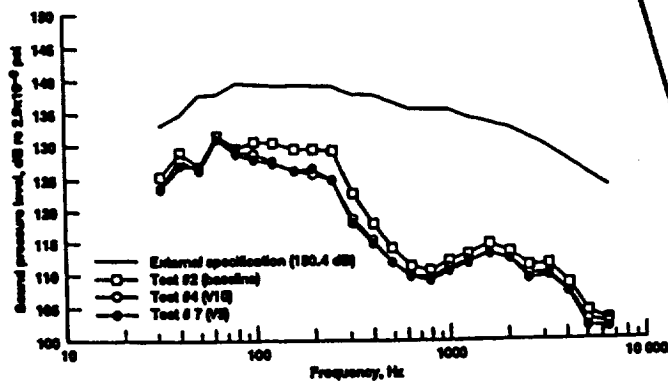


Figure 4. Effect of blanket type on PLF interior acoustics.

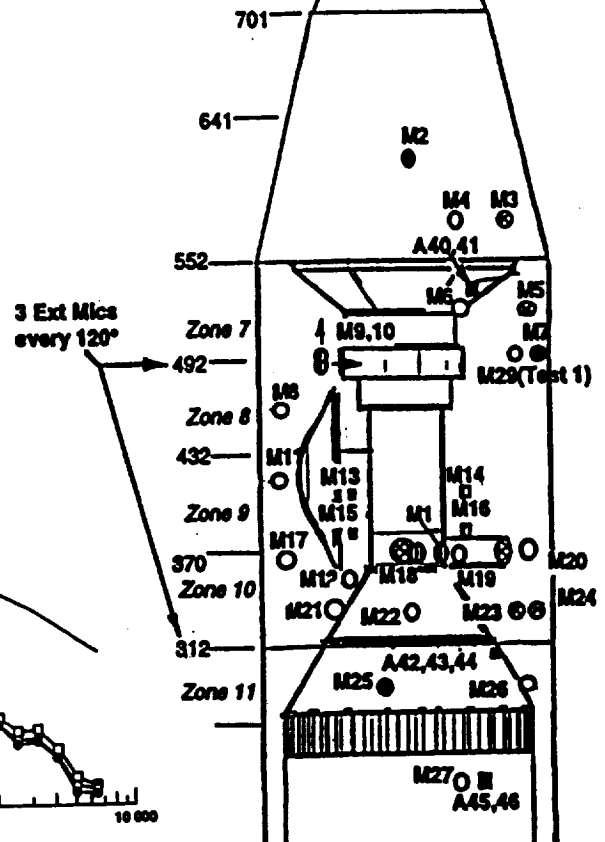
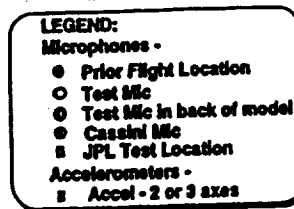


Figure 3. Configuration and instrumentation locations for Phase 2 testing.

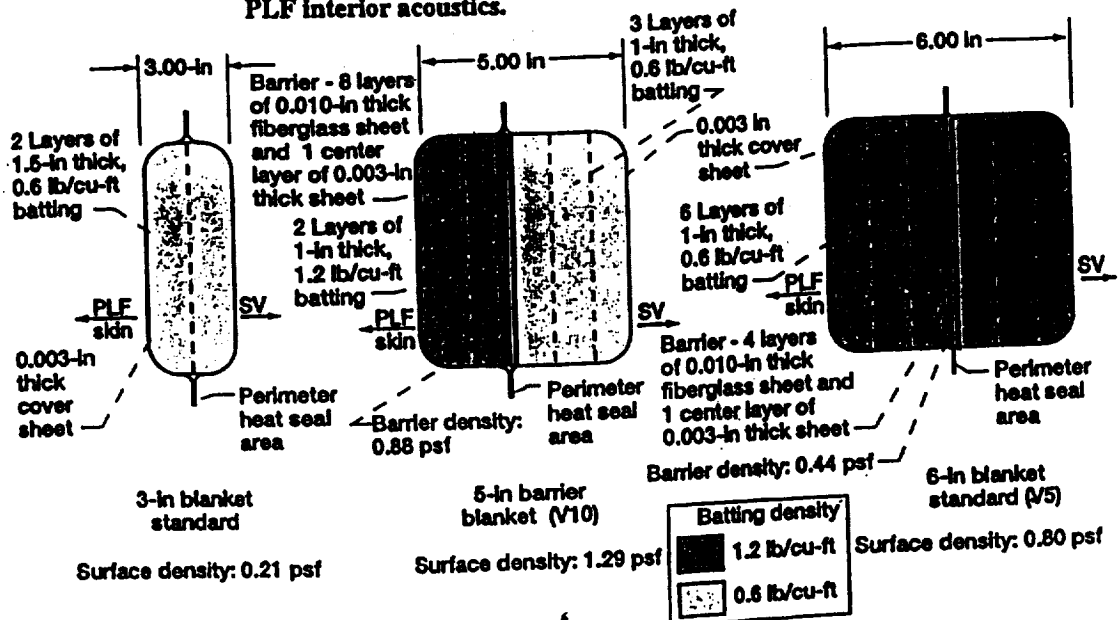
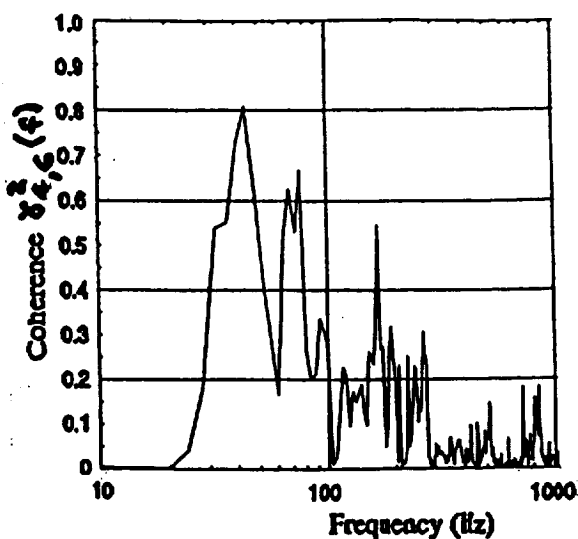
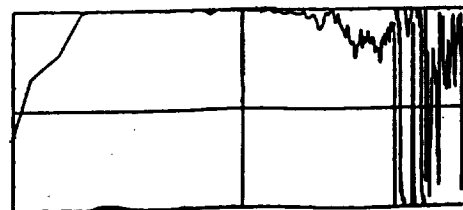
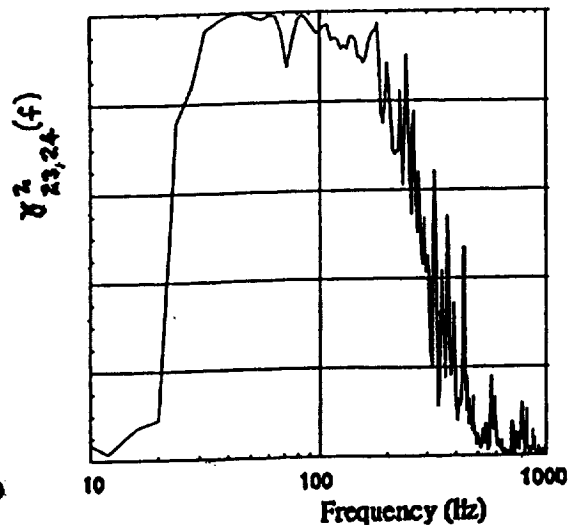


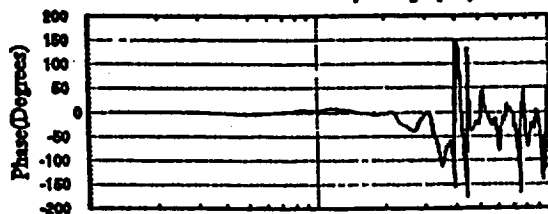
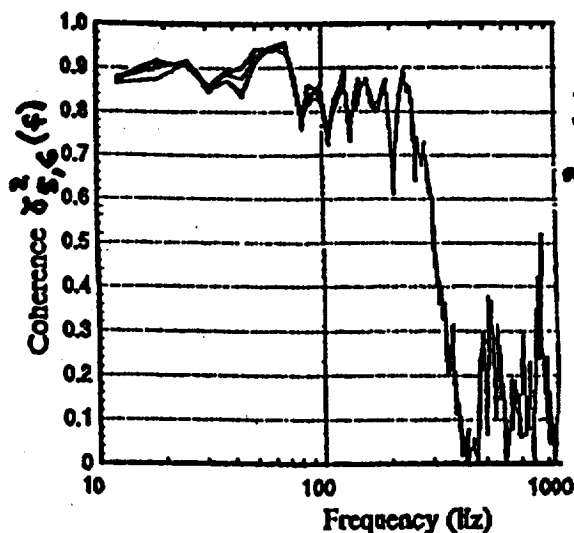
Figure 2. Blanket designs used in Phase 2 testing.



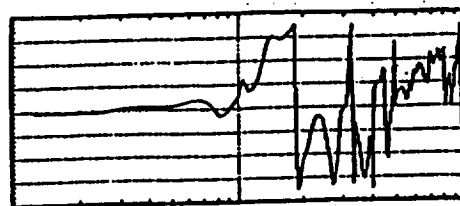
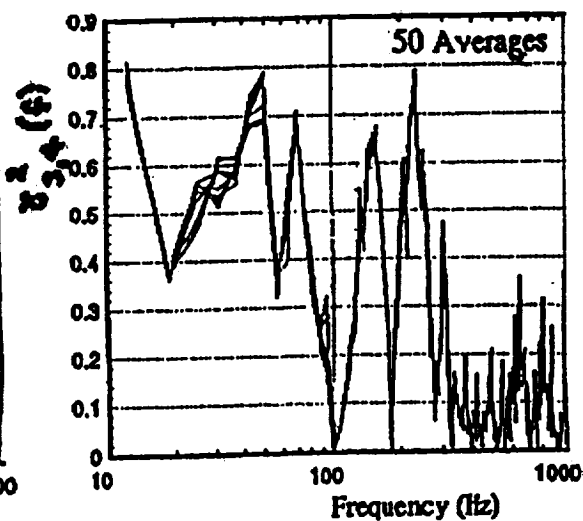
Figures 5 & 6. Coherence spectrum and Phase Angle for Mics 4 and 6 on opposite sides of HGA during reverberant acoustic Phase 2 Test 7.



Figures 7 & 8. Coherence spectrum and Phase Angle for Mics 23 (18-inch standoff) and 24 (PLF surface) during reverberant Test 7.



Figures 12 & 13. Coherence spectrum and Phase Angle for Mics 10005 (18-inch standoff) and 6 (PLF surface mounted) during Cassini liftoff.



Figures 14 & 15. Coherence spectrum and Phase Angle for Mics 10003 and 10004 on opposite sides of the HGA during Cassini flight liftoff.

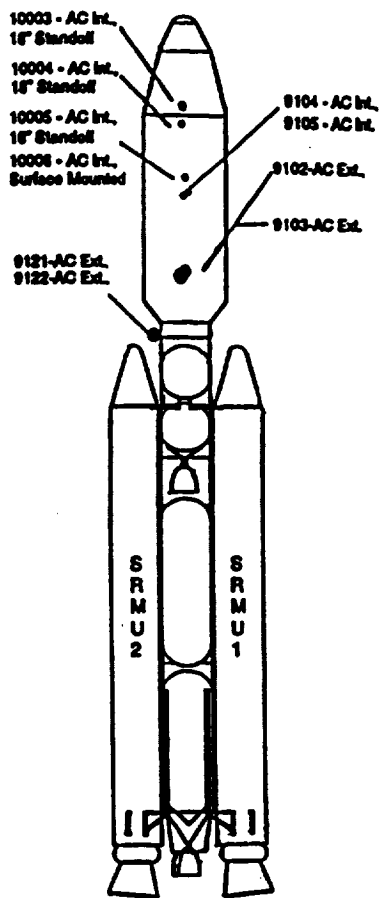


Figure 9. Acoustic flight measurement locations for Titan IV B-33. ¹⁴

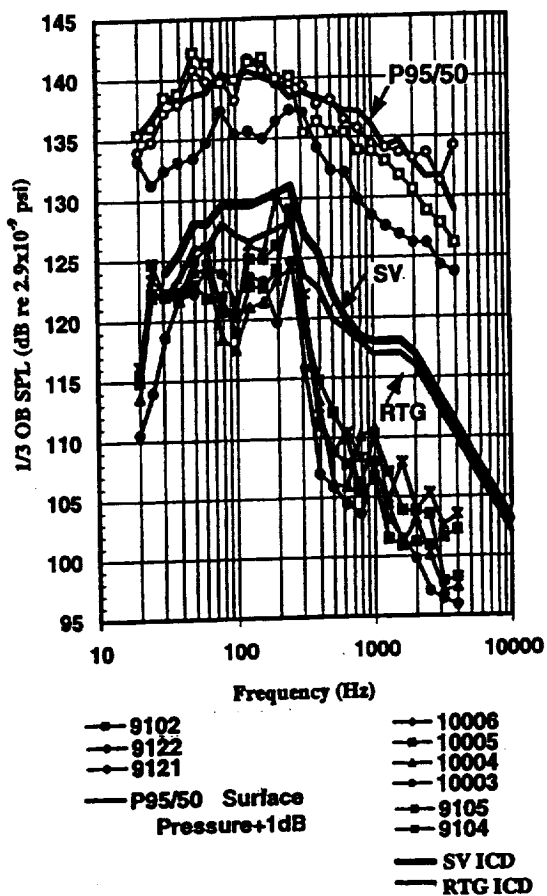


Figure 10. Cassini acoustic flight data at liftoff.

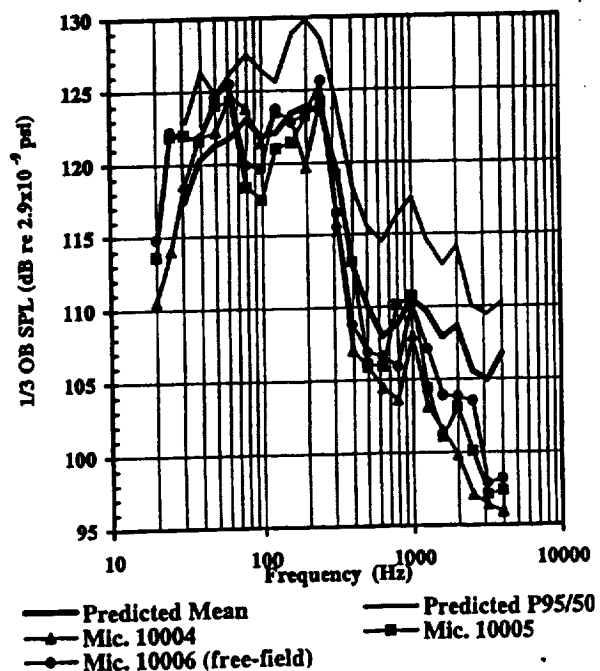


Figure 11. Cassini PLF internal flight data versus pre-flight predictions.